PV Power Plants Layouts

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Webinar Presenter

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This Transcript

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Oriol

Good morning and welcome to the International Solar Alliance Expert Training Course. My name is Oriol Gomis-Bellmunt [inaudible] session, which deals with PV power plant layouts. The support of this expert training experience by the International Solar Alliance, the Clean Energy Solutions Center, and the Carbon Trust.

About me I can say I am professor in Electrical Power Department of the Technical University of Catalonia and one of the professors in charge of the research groups inside UPC. We work with creating international renewable power, especially for the world _____, and also we work _____ power system dominated by power electronics. In this topic we have been doing research in many research and technology transfer projects in the last years.

This session is part of the Module 4, which deals with technical integration of solar. In the previous session we discussed about solar PV methods, about how _____ work and the main principles regarding the behavior of _____. In the session today we are going to talk about the PV power plant as a whole, so it is a plant, including a number of different matters.

This session is organized in different parts. First of all we will talk about the topologies for PV power plants; later we will talk about panel/string /central inverter configurations for PV power plants. The way we present that is out of a paper on the analysis of PV power plant layouts. We will discuss auxiliary equipment for PF power plants, and finally we will also discuss integration of energy storage combined with PV power plants.

Our collection systems for the PV power plants we can say that typically it is addressed with a medium voltage AC network. This is the configuration in most of the PV power plants we have worldwide. The network can have a radial, ring, or star structure, depending on the _____. DC collection is an alternative which is being investigated in some research projects. It could provide some advantages, but it requires more power electronics converters to adapt the voltages. In this case, instead of using transformers to adapt the voltages we need these power electronics. Large DC-AC inverters at medium voltage would be needed to interconnect with the main grid. So we will need this converter to do the connection in the main network, which it will be AC.

About the different configurations we have mentioned previously we can start with the radial collection configuration. In this case we can see that each inverter is connected to a number of strings with four amps. Then we have a transformer which connects the system to the medium voltage network which is doing the collection. In this case we have the radial collection so its inverter is connected to the next one and to the next one until there is a connection to the main medium voltage bus. At this point we have a transformer which adapts the voltage to the transmission network where we can connect.

The reliability of this system can be improved if we move to the ring collection. In this case there is no wire _____ connection between the different units but we have a ring which allows the power to flow through different bus. For example if we have a fault in one of the cables between two inverters the power could flow through the other part of the ring. This provides advantages in terms of reliability, but of course it thus increases the cost of the power amp system. Different ring systems can be implemented. One option is to use two different _____ strings and interconnect them at the end. And the other one is to have a cable _____ 30 inch connecting to the main medium voltage plants.

Another option is to implement what we call a star collection. In this case it's _____ units, instead of connecting to the medium voltage plants. We can see that this is _____ to implement it in specific cases where, for geographical and topographical reasons can force us to employ this solution because normally we will need much more length of cable to install it, to implement the same functionalities.

You can see that one option is to send one cable from each _____ to the main medium voltage plants and another option is to collect a number of [inaudible]. That solution would belong to the star collection solution.

Also we have different topologies. They are how we are connecting the strings and how we are connecting the whole system to the AC network. The first option is to employ what we call a central inverter solution. In this case we have a number of different strings. In each string we have a number of panels connected in series, and then a number of those strings connected in parallel and connected to the power converter.

Another option is to use a string converter, so in each of the strings we have an inverter. You can see that in this case we are now connecting in parallel different strings. But each string is like it's reconnected to the so-called string inverter which is _____ connecting to the AC network. These AC converters can we single phase or three-phase depending on the application.

Another option is the so-called multi-string. In this case we have a string converters but these converters are not inverters, are not DC/AC converters, but converters _____ DC converters. So each of the string _____ are _____ converters so the power that is in the _____ strings can be different. But then they have a common DC bus connected to the main inverter, which would be—if we went to the central inverter we have _____ before.

And again, in this case we could see that we are combining the two biggest concepts, the central and the string inverter.

We will present an analysis of some of the concepts we have mentioned in the previous slide, including that we will use the work from Mikhail Deprada and other colleagues who wrote the paper: *Technical and Economic Components _____ Electrical Collection Grid Configurations for Large PV Power Plants*. In this study different configurations are analyzed and compared numerically. So it is useful for having this session to be able to compare different solutions.

In this case we are considering a system with trackers. So in each of the trackers, which is this rectangle here, we have a number of different strings, and in each string we have a number of different units. We have the option of installing one converter for each of the strings inside the tracker. Another option is to use a converter for the whole tracker. And another option is to use a large building block converter for all the trackers in a unit. These blue boxes in the figure show that there is a converter. So we will have steady configurations with different locations of these boxes of these converters and we will analyze the costs and the performance of each of the solutions.

If we go to that first solution it is based on using a central inverter per tracker. So if we remember some of the previous modules we have strings with a number of panel connected in series. You see that we have several different strings here; they are all connected in parallel and then we have what we call here a central inverter per tracker, which is this green rectangle with the converter. So in each of the trackers we will have a converter like this. The output of this central converter is connected in parallel in the base system. That is the configuration 1 in this study.

Okay, in this configuration a group of PV modules is connected in series forming strings which in turn are connecting in parallel through string diodes to a central inverter per tracker. The key characteristics for this configuration are that power losses due to centralized MPPT are important. We have losses because we cannot optimize the MPPT of the different balance of the different things. So we will have significant losses related to activity.

Also we have mismatch losses between the PV modules because of the different voltages in the PV modules. We have losses in the string diodes. And we have poor reliability since an unscheduled inverter fail leads to the energy loss of a whole tracker or array. So we will have significant losses because of this. The main advantage of this system is that we need low investment costs. It is a solution which is not expensive, and also it has a

_____ inspiration—we have less converters to install, so it will be easier to install this configuration.

We can now move to the so-call configuration PV2 which is based on string inverters. In this case we are installing inverter for each of the strings, which is a DC/AC converter. So we will have much more from that first converter to the use case but its converter _____ of less _____ we will have smaller converters. In this case we do not have losses associated with the string diodes, and it better provides MPPT on a string level.

And we have seen that this is especially useful for those cases where modules are installed with different orientation, or have different specifications because they can still be different gradation, so the MPPT will be—will better arrive to different voltages and it makes sense to have a string, inverters in this case to other [inaudible].

This solution increases the reliability in comparison with PV1 since a failure of a string inverter does not imply the loss of the total PV power plant but only a small part of it.

But the problem is that it increases the cost and complexity compared to PV1. So we have more performance but also it will be more expensive and more difficult to install.

Another option it so to go to PV3, which multi-string inverter, one of the solutions we mentioned before. In this case several strings are interfaced with _____ DC converters, which are connected to a common center inverter. So you see that the different strings, each of them has a DC converter so we can control the _______ the voltage of each other's strings and implement in the _____ reliability in each of the strings. Then we have a common DC voltage of the DC box, and then _____ to the AC network. Compared to PV1 this solution [inaudible] efficiency. We have much better performance. It is suitable to connect the strings with different orientations or different degrees or chains. We cover the same we commented in the previous degree too.

The DC/DC converters increased the voltages to that both wiring costs and the costs associated with cable losses are reduced. And this is an important advantage. And finally, it increases the investment costs on the converters compared with both PV1 and PV2.

It is also possible to go to _____ a converter compared to PV1 and install it from each building block. So in this case we have only one central inverter per building block. And this is the configuration PV4. In this case the complexity of the installation and investment costs are substantially increased. We reduce a lot the number of inverters we need in the system. They will be much larger but normally this is much better from the economic point of view.

The problem, as it is [inaudible] is that the energy yield efficiency is diminished because of the reasons we discussed about before. We cannot optimize particular PV; we are very far away from that because we have a huge number of panels connected to our _____ inverter, so it is not possible to optimize the _____ for all of them. And also the reliability losses of this particular configuration are higher than the previous cases because [inaudible] in the inverter will _____ quite a loss of energy ______.

It is possible to combine this converter, this inverter per building block DC/DC converters in the trackers. And this is the configuration PV5. In this case we see that we have the DC/DC converter for the tracker so we are connecting a number of parallel strings with the DC/DC converter to a central bus, and then we have an inverter for the whole building block.

This is a combination between PV1 and PV4. As we said, each tracker is connected to a DC/DC converter, which performs an MPPT control strategy similar to the aforementioned central inverter of PV1 topology. Likewise, each building block has installed one central inverter which connect the DC outputs of all DC/DC converters and delivers the AC power to the point of common coupling.

The key characteristics of this solution are that it has enhanced energy yield efficiency by reducing the MPPT losses in comparison with PV4 without increasing the investment costs and the complexity of installation of the system. Also the inclusion of DC/DC converters allows to step up the voltage, thus reducing cable losses beyond the tracker's output.

The PV configuration presents similar drawbacks as PV1 topology in terms of high mismatch losses between the PV modules and significant MPPT losses within each tracker, and so reliability losses, as in PV4, due to a lack of power of an entire building block in case of failure of a single central inverter.

Other possible configuration is PV6. In this case we have DC/DC converters for each string and a central building block inverter. As we can see in the figure the DC/DC converter is connecting the string that we're going to have converter for the tracker and we have a central inverter for the whole building block. This is an adapted combination between the previously-discussed PV2 and PV4 concepts. Each string of each tracker is controlled by a dedicated DC/DC converter, which provides MPPT control. All the string inverters are connected to a common centralized inverter.

The key characteristics of PV6 are that it avoids losses associated with the string diodes and increase the energy yield efficiency by decreasing the mismatching losses and partial shading losses. The other characteristic is that -- and also the main drawback, is that high cost and complexity of installation due to the large number of electronic devices required.

So with these six configurations that were mentioned before by Deprada and other colleagues is _____ analysis and comparison of all the different systems. To do this analysis it takes data from specific location in Colorado, USA. Here we see that we have data for different power capacities of 150 and 200 megawatts. And here we see the number of modules, number of strings, _____ building blocks and also the area occupied for all these three different configurations.

The analysis as made with this meteorological data here in the slide we see the sun azimuth versus elevation angles for each hour of the whole year. And this is that data employed in order to calculate the performance of the power plant using the different configurations we have been discussing about.

More data on the meteorological data here see the variation for different months of the year and this is [inaudible] variation considering soiling, IAM factor and shading losses over a whole year.

In order to compare the different configurations we have talked about we are going to use different indicators. One is the performance ratio, the PR, and the other ones are economical indicators. The performance ratio is defined as the energy injected to the grid divided into the irradiation of the plane of array times the array efficiency. So basically _____ defines the ratio between energy we are actually injecting and the maximum energy we will inject.

The difference between these two energies which makes the PR ratios are related to different losses, which are considered -- these losses include the soiling losses, that means the incidence angle modifier, IAM, the shading losses, the PV conversion losses, the losses related to the MPPT implementation, losses related to the aging of the system, the inverter losses, cable losses, transformer losses and reliability losses. So all the possible losses _____ are considered in the performance ratio calculation. So it is a very good indicator of how good the system is performing.

And here we see the results: the maximum value for the PR is 1, and we see that for all the different configurations we have been talked about we are obtaining their values we see in the figure.

You see that normally for one megawatt power plant, you obtain higher PR compared to the 50 and 200 megawatt and this is because the study is considering also the collection ____ losses, the losses in the HC network. So if we have one megawatt the power plant is a smaller, so we have less electrical losses in there. This is done [inaudible] is 1 megawatt power plant perform better.

If we look at the capital cost for all the different configurations here we see the result. The result is [inaudible] divided into the megawatt of power, and we see that we have different costs for each of the configurations. We can see that the one with lower cost is PV4, which was the one with one converter per building block which is largely economical because it uses much less converters compared to the other ones, and the most expensive one is PV3, where we have an inverter for each of the strings.

You can also see here that the costs include all the different costs of different parts of the system, so we see the cost for _____ DC/DC converters and the cost of obtaining ____, the cost of the transformers, the status systems, PV modules, [inaudible] and AC/DC cables. You can see that in the cases where we need the DC/DC converters we have the cost of DC/DC converters, we have PV3, PV5 and PV6 because these other cases where we have two converters in the system with the [inaudible] AC. I think the other ones we do not include the cost of DC/DC converters because they are _____.

The capital cost is telling us how much the system costs and previously the [inaudible] was telling us how the plant is performing. But a very good number, a very good indicator so summarize how good and technically how good a solution is the so-called levelized cost of energy, the LCOE.

LCOE is telling us how much does it cost to produce a megawatt _____ of energy and _____ solution. And here we see that we have differences in the LCOE for the different configurations. _____ we see that one which is obtaining the best LCOE, so the one producing energy at a lowest cost is the PV4, the one with ____ converter per building block. And so we have information on the different sizes of the power plant and we see that in this case the one with 200 megawatts is the one with lowest LCOE, which is [inaudible] power plant is, the lower the cost of energy is for the power plant.

Next we can see some more information on the LCOE as it is [inaudible] related to different component reliability cost. We see that when reliability is high LCOE, that lowest line, is PV4. But we see that if we increase the cost of that we reduce the reliability of the system, the parameters related to reliability, and the costs are not changing, but still the PV4 is the one with lowest LCOE. But you see that the cost is changing _____.

We will talk also about remunerating the PV power plants. Until now we have been talking much more about the PV panels and inverters, but also the PV power plants require much more equipment, which is very important to take into account. First of all we need interconnection cables and lines to connect all the different part of things like the strings, and then on the AC side to interconnect all of the different backups and to connect to the point of connection, to the main grid _____ we need substantial amount and length of cables and lines. Also we need grid connection equipment and this includes protection equipment, and basically we need protection relays to detect and locate the faults. Also we need electrical switchgear to operate the grid whenever it is needed. [Inaudible] isolators and different switchgear are needed _____ PV power plant. We need power transformers _____ the voltage. We have said that normally based on _____ allocated near the backup. So when backup is working at low voltage and then with the transformer we can elevate the voltage to medium voltage level. And then we will need also transformers in the point of connection to the transmission needed in that _____ when we are connecting to the transmission grid to _____ the voltage from medium voltage level to high voltage level. Also we can get reactive power compensation equipment and in some projects we can also need energy storage systems.

If we look at the costs of this system we can see the following information. If we look at the total cost of the photovoltaics we see that the significant _____ related to the modules and inverters. You see here is this part. But also we get another part which is the so-called balance of system cost. This balance of system cost includes the following items. So we can notice here that it is very relevant, so it's the cost of infrastructure, the cost of grid connection, the cost of DC cable, the cost of installation and the cost of marketing. [Inaudible] and all of these are very important, so we need to take into account all these elements from this when _____ PV power plant.

We have different possible configurations for the PV power plants. One of them is that we design them in an application where we have stand-alone power plants because we're going to have availability to connect to the main network or because we do not want to connect to the main menu. And in this case we will have the PV power plant with other different modules. We will have switchboards to connect the different strings. And then in that connecting to the AC load we have in this case that it leads to this house here to present an AC load. And in a region we have to understand a lot of systems and we note that we know that the PV power is entirely _____ by _____ and changing a lot during the day. We need other sources of energy to supply the _____ household when the sun is not available. In this case we will have a storage system based on battery, which is number four, and typically we will also have all other energy supplies like you might see here, like a diesel generator for _____ which can supply energy in the case we do not have availability of the battery and availability of the solar radiation.

Another possible application which is much more simple it's the connection of the PV power plant to the grid. In this case you see that you have a string with a number of different solar panels. You have the switchboards connecting each of the strings together to the DC paths of the converter, and then you have the converter/inverter converting DC to AC and taking this power to the main grid. In this case the configuration is much more simple because we do not have energy storage _____ any sources of energy to supply the loads.

In large PV power plants we may get a number of units, a number of inverters and the size of the inverters typically employed and in the range from some kilowatts to some megawatts. So typically the typical size of solar PV inverter is one megawatt. Also we have some manufacturers supplying powers of up to five megawatt but not typically less than that.

So if we have a very large PV power plant we need to design it to have a number of different inverters distributed throughout the power plant. Typically these inverters are connected as it is shown in the figure so we have in this case a one megawatt central inverter which is connecting a number of PV panels to the AC system. Then we have ____ arrangement where we have two low voltage windings, one connected to one inverter, another one connected to another inverter and finally a medium voltage winding which is connecting to the medium voltage PV. This is a typical arrangement which is employed in many projects. And then there are some savings related to the organization of the transformer for this particular solution.

Here we can see some more detail on this, typically the inverter will be operating at low voltage, below 1,000 volts in the AC side. So we would have later a transformer to regulate the voltage to medium voltage. And then we have some switchgear to connect to the medium voltage gear.

In some cases we will have a single feeder; in other cases we will have a double feeder configuration for the medium voltage gear.

We know that our _____ is needed to supply reactive power. This will be an important requirement and we will discuss about the event of being about integration of PV power plants to the main system. We will see that depending on the voltage at the point of connection we'll be needing to supply or absorb reactive power. In some cases the reactive power can be provided by inverters. We were discussing in the previous session that solar PV inverters were voltage source converters, and these converters have capacity of controlling independently active reactive. So these converters can absorb or inject active power whenever it is needed.

But also we said that there are some limitations on that, and their so-called ability _____, which limit the amount of active power that the inverters can inject. And depending on the point of operation, for example when they are operating at maximum active power we see that we have to produce the amount of reactive power they can inject.

For this reason in some applications it is needed to provide additional reactive power with additional equipment. This reactive power can be provided with capacitor banks -- this is the most typical and easiest solution we are using fixed capacitors. Normally we arrange them in a way that we can connect a different number of them, depending on their needs. So we can connect 1, 2, 3, 4, 5, a number of capacitors which is needed for the situation. But the transition from connecting one to the next one is not continuous. So we will see an important change in reactive power when connecting any capacitor bank.

For this reason we say that these connect provide good dynamic response. _____ we need a small _____ response, without dynamic response of reactive power we cannot use capacitor banks. Also, if we need to inject reactive current when there is a fault or _____ which we will see is a requirement in some countries of the world, these capacitor banks will not work in that case because if the voltage is lower _____ the capacity _____ they will inject will be lower. So they will not be fully _____ in this case.

Another option is to use a static VAR compensators, as we see, which are one of the converters which are FACTS in power systems. FACTS stands for flexible AC transmission networks. And these kind of systems can be used to provide reactive power using electronics, basically switching _____ which in practice makes a valuable _____ capacitor. So we can adjust dynamically -- one can adjust dynamically the reactive power. So what can be used, for example for voltage control and they have the most response. But again, as seen what happened in the previous case, at least a fault, as we see converters cannot provide [inaudible] reactive power.

If we need to do that we need to go the other solution, which is a STATCOM. A STATCOM is a static synchronous compensator which can inject reactive power dynamically and also it can inject reactive current when there are fault conditions. So [inaudible] inject active _____ in basically any _____. This is based on voltage system _____ which as we know can counteract reactive power -- they us reactive power to keep the STATCOM connected and the voltage in the DC banks and then they control reactive power at any time and conditions.

In some applications we can us capacitor banks for the bulk reactive power provision and a STATCOM for the regulation. This will be an optimal solution; it is employed in several large PV power plants in the world. So the bulk amount, max amount of reactive power is provided by capacitor banks, and it is changing with steps as we said before, and then the _____ regulation is provided by STATCOM.

Energy storage systems are needed in some large PV power plants. Again, we are going to discuss a lot of these in other sessions, where we will talk about different requirements, which force PV power plant to use energy storage. One of the environments is for example the ramp control. When the RPLs are cloud _____ power generation from the PV power plant _____. And then we need, if we want to fulfill the requirement from the power system we need to keep the power increasing not so fast. If we want to do that the best solution is to use energy storage systems. Okay, so this is one of the _____ areas. But we will discuss all of that in another session. In the session today basically we want to describe the different electrical energy storage solutions which are available and in another session we will discuss how to us them.

Basically electrical energy storage systems can be classified between mechanical, electromagnetical, electrochemical solutions. Mechanical solutions include pumped hydro energy storage, which is probably the one most used in power systems nowadays. Also the compressed air technology, and also the flywheel, which basically _____ energy _____ a rotating axis. Electromagnetic energy storage solutions can be supercapacitors or SMES, which means the superconducting energy storage. And finally electrochemical electrical energy storage systems can be based on hydrogen, flow batteries or other batteries. Here we have a list of the different technologies available.

All these different electrical energy storage systems we have different time scales where each of the solutions is more appropriate. For example we see that for long-term energy storage, hours or days, we can use hydro compressed air or hydrogen. In this case we can store energy for long time periods and it is efficient and it works probably. If we have a medium-term energy storage we can use all the other electrochemical solutions, basically all the different batteries which can work properly for minutes to hours. If the time scale is short, only second or minutes, it is more appropriate to use flywheels, _____ supercapacitors or SMES.

Here we see that we can put some examples of each of the technologies we described before in this axis wherein for the horizontal axis we have the power rating for each of these technologies and in the vertical axis we have the energy rating for each of them.

So we see that in some cases we have high power and low energy or high energy and low power, and depending on the application we can choose one or the other. It is interesting to see that we have these diagonal lines where we have constant time because if we divide energy into power we have _____ time. So basically we have obtained a time constant or a time where when the energy storage system can inject the nominal power to the system.

So we see that the ones with higher time are these hydro systems and the ones with lower time are the SMES system, the superconducting _____. Also it is important to look at the level of maturing of each of the technologies. We see some of the technologies are well-developed, commercialized since long time ago. This is the case, for example, of storage hydro, which has been used since many years ago and it is completely mature and proven technology, but other solutions, I mean _____ are in research and development and others are being in demonstration nowadays. So when I was looking at the costs of each of the technologies it is important to take into account in what stage of development we are.

Looking at the applications here we have a table where we can look at all the different technologies available from hydro, hydrogen, compressed air, all of them until the supercapacitors, and also we have different possible applications. Before we have discussed a bit about the -- when to use each of the technologies depending on how long we need to store the energy. But here we see also some different applications. For example we see that fluctuation suppression we can use some of the technologies, but it would not be useful, for example, to use pumped hydro for this particular proposal. For low voltage ride through again we see that something like this could be used but not at low strength right? So in terms of the table it shows applications for each of the different energy storage systems.

Here we see how in the world we are using energy storage. So basically we are counting the number of projects, research projects where we are using energy storage for one of the applications here. And basically we see -- and this is why we are introducing this topic here, that one of the most important applications of energy storage in the system is the integration of renewables. So when talking about integration of PV or integration of wind energy storage is very useful. So many research projects are _____ at this specific application.

And in these projects we can see that the intense research activities should favor a dramatic cost reduction of lithium-ion batteries in a short term, thus favoring a generalized deployment of this technology in the electrical power system and the electro mobility fields. The European Commission, and other organizations proposed that in all the roadmaps the objectivity of decreasing by a factor of five the current cost of lithium batteries by 2030.

So here we see how the costs are changing and how we expect the cost to change in the next years. We have seen -- we have talked about lithium ion; also we have other technologies of batteries, and we see that the costs are getting lower and lower and we expect max _____ costs of 2050.

When looking at the possible application of batteries or energy storage systems we see that the costs of the energy storage systems are high. Of course the benefits are important, but for example we look at frequency regulation; we see the possible benefit is for example this one. If we look at the integration of electric vehicles it's this one, voltage control is this one; load following is this one; transmission and distribution infrastructure is this one.

So normally when we do technical economical analysis about studying if we should explore an energy storage system for one of these particular applications we see that the cost is much higher than the benefit we obtain. What makes sense is instead of considering only one of these specific applications is to look at what happens if we are addressing more than one application. Ideally we could address all of these applications with a single energy storage system. If we do that we can assume all the benefits from one of them and we can see that the benefits are higher than the costs.

So there is a clear potential here of designing energy storage systems which can be used in many different applications. The challenge here is that _____ the controllers implement will need to include all these functionalities and finally we will need to prioritize some of them against the others because doing some instance _____ is not possible to do the actions which would benefit each of these applications. Okay, so then it will be very important to design our items to prioritize the different benefits and to ensure that the system works properly.

Well, we've come to the end of this session. We can finalize the session with a summary of the most important messages we have included in the presentation. First of all we can say that collection systems for PV power plants can be implemented with radial, ring or star systems. We have been seeing all these possible configurations. PV power plant collection is typically designed at medium voltage. There are number of possible topologies for arranging the power inverters, including central, string and multi-string converters. We have discussed each of them and also we have included the analysis showing different solutions for one example. And also we need additional equipment, including transformers, switchgear, and in some cases reactive power equipment and energy storage systems.

And this is the end of this session. Thank you for your attention.